USACERL Technical Report FE 93/23
August 1993
Energy, and Energy Conservation

AD-A273 339

US Army Corps
of Engineers
Construction Engineering
Research Laboratories

(2)

Selecting Effective Fluorescent Lamp and Ballast for Retrofit in the Continental United States

by
William R. Taylor

DTIC
ELECTE
DEC 0 3 1993
S A

Electrical lighting is a major contributor to daytime peak energy demand, accounting for about 30 percent of total electricity consumption in most Army facilities. Some of this energy may be wasted because many existing lighting systems at Army Installations use outmoded technologies.

While recent technology has improved the energy efficiency of all lighting systems, fluorescent lighting—the most widely used interior building lighting—has shown the greatest efficiency gains. Retrofits using high-efficiency fluorescent lamps and ballasts can yield significant operating cost savings. High-efficiency fluorescent lighting systems are widely available, but current information on their performance characteristics is highly technical and not easily accessible to Army facility managers considering retrofit options. This report provides a single, accessible source that summarizes fluorescent lamp and ballast performance characteristics and outlines selection procedures.

93-29428

Approved for public release; distribution is unlimited.

93 12 2 079

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED

DO NOT RETURN IT TO THE ORIGINATOR

USER EVALUATION OF REPORT

REFERENCE: USACERL Technical Report (TR) FE-93/23, *Selecting Effective Fluorescent Lamp and Ballast for Retrofit in the Continental United States*

Please take a few minutes to answer the questions below, tear out this sheet, and return it to USACERL. As user of this report, your customer comments will provide USACERL with information essential foı improving future reports.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

____

____

____

2. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.)

____

____

3. Has the information in this report led to any quantitative savings as far as manhours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

____

____

4. What is your evaluation of this report in the following areas?

a. Presentation:______________________________

b. Completeness:______________________________

c. Easy to Understand:______________________________

d. Easy to Implement:______________________________

e. Adequate Reference Material:______________________________

f. Relates to Area of Interest:______________________________

g. Did the report meet your expectations?______________________________

h. Does the report raise unanswered questions?______________________________

i. General Comments. (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.)

____

____

____

____

____

5. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: _______________________

Telephone Number: _______________________

Organization Address: _______________________

____

____

6. Please mail the completed form to:

Department of the Army
CONSTRUCTION ENGINEERING RESEARCH LABORATORIES
ATTN: CECER-IMT
P.O. Box 9005
Champaign, IL 61826-9005

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
August 1993

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Selecting Effective Fluorescent Lamp and Ballast for Retrofit in the Continental United States

5. FUNDING NUMBERS
MIPR
E87900273

6. AUTHOR(S)
William R. Taylor

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Construction Engineering Research Laboratories (USACERL)
P.O. Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
TR-FE-93/23

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineering and Housing Support Center (USAEHSC)
ATTN: CEHSC-FB-S
Bldg. 358
Fort Belvoir, VA 22060-5516

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Electrical lighting is a major contributor to daytime peak energy demand, accounting for about 30 percent of total electricity consumption in most Army facilities. Some of this energy may be wasted because many existing lighting systems at Army Installations use outmoded technologies.

While recent technology has improved the energy efficiency of all lighting systems, fluorescent lighting—the most widely used interior building lighting—has shown the greatest efficiency gains. Retrofits using high-efficiency fluorescent lamps and ballasts can yield significant operating cost savings. High-efficiency fluorescent lighting systems are widely available, but current information on their performance characteristics is highly technical and not easily accessible to Army facility managers considering retrofit options. This report provides a single, accessible source that summarizes fluorescent lamp and ballast performance characteristics and outlines selection procedures.

14. SUBJECT TERMS
fluorescent lamp
ballast
energy conservation
retrofit
lighting

15. NUMBER OF PAGES
26

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

FOREWORD

This work was done for the U.S. Army Engineering and Housing Support Center (USAEHSC), Fort Belvoir, VA, under Military Interdepartmental Purchase Request (MIPR) no. E87900273, April 1990; Work Unit W10, "Energy, and Energy Conservation." The technical monitor was William Ell, CEHSC-FB-S.

This study was done by the Energy and Utilities Systems Division (FE), of the Infrastructure Laboratory (FL), of the U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was William Taylor. Research for this study was performed by Enviro-Management & Research, Inc., Springfield, VA, for Lawrence Berkeley Laboratory, Berkeley, CA, under contract no. DACA 88-90-D-0023. Dr. David M. Joncich is Division Chief, CECER-FE, and Dr. Michael J. O'Connor is Laboratory Chief, CECER-FL. The USACERL technical editor was William J. Wolfe, Information Management Office.

LTC David J. Rehbein is Commander of USACERL and Dr. L.R. Shaffer is Director.

Accesion For	
NTIS CRA&I	√
DTIC TAB	
Unannounced	
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and / or Special
A-1	

CONTENTS

SELECTING EFFECTIVE FLUORESCENT LAMP AND BALLAST FOR RETROFIT IN THE CONTINENTAL UNITED STATES

1 INTRODUCTION

Background

Electrical lighting is a major contributor to daytime peak energy demand, accounting for about 30 percent of total electricity consumption in most Army facilities. Some of this energy may be wasted because many existing lighting systems at Army installations use outmoded technologies.

In the past decade, improvements have been made in the energy efficiency of all lighting systems, creating opportunities to dramatically reduce lighting energy use while providing better illumination. Of all lighting systems, fluorescent lighting—the most widely used interior building lighting—has shown the greatest efficiency gains.

Retrofits using energy-efficient fluorescent lamps and ballasts can yield significant operating cost savings for the Army. High-efficiency fluorescent lighting systems are widely available, but current information on their performance characteristics is highly technical and not easily accessible to Army facility managers who are considering retrofit options. There is a need for a single, accessible source that summarizes fluorescent lamp and ballast performance characteristics and outlines selection procedures.

Objectives

The objectives of this study were to test and analyze an available electrical energy conservation technology—fluorescent lamps and ballasts—and to develop an approach for selecting and implementing the retrofit technology.

Approach

A literature search of manufacturers' information and recent scientific research was done to gather information on the current state of fluorescent lighting technology. The Lawrence Berkeley Laboratory (LBL) was contracted to test factors that affect the performance of fluorescent lamps and ballasts. The information gained from these investigations was used to develop stepped procedures for lamp-ballast selection.

Mode of Technology Transfer

It is recommended that the results of this study be incorporated into an Engineer Technical Note (ETN).

Product Manufacturers

The following manufacturers are associated with products tested in this study:*

Advance Transformer Co.
10275 W. Higgins Road
Rosemont, IL 60018

Electronic Ballast Technology, Inc. (EBT)
2522 W. 237th St,
Torrance, CA 90505

Etta Industries, Inc.
4755 Walnut St.
Boulder, CO 80301

General Electric Lighting Business Group
Neta Park
Cleveland, OH 44112

GTE Products, Corp., Sylvania Lighting Center
100 Endicott St.
Danvers, MA 01923

MagneTek
1124 E. Franklin St.
Huntington, IN 46750-2575

Philips Lighting Co.
200 Franklin Square Dr.
Somerset, NJ 08873

Valmont Electric Co.
1430 E. Fairchild St.
Danville, IL 61832

Makers of fluorescent lamps and ballasts manufacture a range of products that differ widely in their specifications, and consequently, their performance characteristics. This report does not endorse or imply any endorsement of any specific manufacturer or commercial product.

* General Electric (GE) no longer makes ballasts. Since the conclusion of this study, GE has sold its line of ballast products to Valmont Electric Co.

2 ENERGY EFFICIENCY OF FLUORESCENT LAMPS

Because fluorescent lamps offer good color rendition, are four times more efficient, and last up to 20 times longer than incandescents, fluorescents have become more popular and widely used than incandescents in the United States.

Light in fluorescent lamps is generated by gas discharge. The lamps require a ballast to strike an electric arc in the tube initially, and to provide voltage and current to the lamp while it is on. Fluorescent lamps come in lengths of 6 in. to 8 ft.* The 4-ft lamps are the most common; yet the longer the lamp, the higher the efficiency.

Types of Fluorescent Lamps

Fluorescent lamps generally use one of four shapes: tubular, U-shaped, circular, or double-folded. Lamps with bends are usually made from lead glass; straight lamps from lime glass. Three circuit types are used: *preheat, instant start*, and *rapid start. Preheat/rapid start* (which can operate on either preheat or rapid start circuits) are the most common. *Preheat* lamps require a few seconds to illuminate after they have been activated, and most have a "trigger start" ballast, which heats the cathodes. *Instant start* lamps (also called Slimline) need no preheating because they use ballasts that provide a high starting voltage (400 to 1000 volts) to the cathodes. *Rapid start* lamps require less voltage than instant starts because of their continuously heated, low-resistance cathodes that can start up almost as quickly as the instant start lamps. Most lamps run on standard operating currents of 380 milliamperes (mA) for a 20-W preheat, 425 mA for an instant start (265 mA for T-8 instant start lamps), and 430 mA for a preheat/rapid start. High-output lamps (operating at 800 mA) and extra-high-output lamps (operating at 1500 mA) are available only for rapid start fluorescents.

Fluorescent Lamp Retrofit Options

During the past decade, different fluorescent lamp retrofit options have replaced the once popular standard 40W F40 T-12 lamps. (Note, "T" refers to "tubular" and T-12 lamp designation indicates envelope diameter in eighths of an inch, so that T-12 lamp is 12/8 in. = 1.5 in. in diameter.) These include: energy saving 34W F40 T-12 lamps, energy saving 32W F40 T-12 lamps, 40W F40 T-10 lamps and 32W F32 T-8 lamps. The latter two lamps have higher lamp-ballast system "efficacies," where efficacy is described as how effectively the lighting system converts electric energy into visible light, and is measured in lumens of output per watt of input (lm/W). They also are smaller in diameter than the standard 40W F40 T-12 lamps (Figure 1).

Energy-Efficient 34W F40 T-12 Lamps

Energy-efficient 34W F40 T-12 lamps are filled with an argon-krypton gas mixture rather than only argon (as used in standard 40W F40 T-12 cool white lamps). The lamps are compatible with the ballasts used in standard lamps, but have a lower light output. As such, they are normally used only in over-illuminated areas. Combined with standard magnetic ballasts, the lamp-ballast system has a lower efficacy than a standard argon gas-filled fluorescent lamp-ballast system.

---

*1 in. = 25.4 mm; 1 ft = 0.304 m.

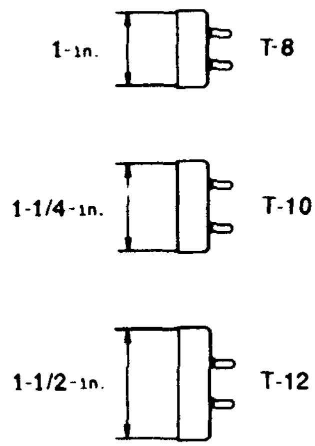

Figure 1. Diameters of T-8, T-10, and T-12 Lamps

Energy-Efficient 32W F40 T-12 Lamps

Energy-efficient 32W F40 T-12 lamps are argon-krypton gas filled with an added heater cutout device (a thermal switch that disconnects the lamp heater filament). After starting, this switch removes cathode heater power with no loss in light output. A limitation of this type of lamp is that a restrike time of 1 to 2 minutes is required to turn the lamp on after it has been turned off.

High-Efficiency Phosphor Lamps

New types of fluorescent lamps are available that use tri-stimulus (rare earth) instead of the halophosphate phosphors traditionally used in standard fluorescent lamps. Whereas halophosphate phosphors emit broadly throughout the visible spectrum, tri-stimulus phosphored lamps (also called "tri-phosphors") emit in three fairly narrow regions of the red, green, and blue portions of the spectrum. Lamps are now being manufactured with layers of both types. These double-layer coatings provide improved color rendering and efficacy at a lower cost than the thick single-coated, tri-phosphors. These lamps should be considered as replacements for the deluxe colored halophosphate type lamps. Table 1 lists some representative values.

40W F40 T-10 Lamps

The 40W F40 T-10 lamp offers higher efficacy, longer life, and increased light output than a standard fluorescent lamp. These lamps are most commonly used as a retrofit for T-12 lamps when no ballast change is needed and where increased light output is required. Currently, T-10 lamps are only available in 4-ft lengths.

32W F32 T-8 Lamps

The 32W F32 T-8 fluorescent lamps are 1 in. in diameter, compared to the 1.5 in. of a standard T-12 lamp. The first T-8 (a 4-ft, 32W lamp) was introduced in 1981. Now the T-8 family also includes

Table 1

Characteristics of Fluorescent Lamp Phosphor Coatings

Lamp Type	Standard*	Tri-Stimulus Single "Thick" Coat	Tri-Stimulus Double Coat
Initial lumens	3050	3275	3250
Mean lumens (%)	87.9	87.9	88
Initial lumens/watt	76.3	81.9	81.3
Life (hours)	20,000 @ 3 hours or more/start		
Color rendering index	62	[illegible]	70

* The table values apply to a 40W rapid start fluorescent lamp. The double coat phosphor is a two-layer coating consisting of a layer each of the standard and tri-phosphor materials. Chromaticity (apparent color temperature), which is a measure of the visual warmth or coolness of a particular lamp color, is rated as the same for the three designs.

Table 2

T-8 Lamps

Watts	Rated Light Output (Lumens)	Lamp Efficacy* (Lumens/Watt)	Rated Life* (Hours)	Lamp Length
Straight lamps				
17	1350	79.4	20,000	24 in.
25	2150	86.0	20,000	36 in.
32	2900	90.6	20,000	48 in.
40	3650	91.3	20,000	60 in.
U-shaped lamps				
16	1250	78.1	20,000	10.5 in.
24	2050	85.4	20,000	16.5 in.
31	2800	90.3	20,000	22.5 in.

* Lamps operated at 60 Hz in the rapid start mode (does not consider ballast losses).

2-ft (17W), 3-ft (25W) and 5-ft (40W) lamps. Since 1985, the T-8 family has also included three U-shaped tubes. A summary of the characteristics of the T-8 lamp family is provided in Table 2. The largest U-shaped lamp is ideally suited for 2x2-ft luminaires. These provide the equivalent light of a 2x4-ft luminaire while saving a significant amount of energy. Two of the smallest U-shaped lamps can be installed in a 1x1-ft luminaire to provide the equivalent light output of a 150W incandescent luminaire while consuming only 42 W.

The T-8 lamps have good color-rendering properties and are available in three color temperatures: 3100 K, 3500 K, and 4100 K. All have the same lumen rating (2900) and color-rendering index (75). Their good color is the result of the use of rare earth phosphors. The phosphors also help to give the T-8 family unsurpassed efficiency among fluorescent lamps. A 32W F32 T-8 lamp with an electronic ballast operated in an instant start mode (no filament power) is the most efficient fluorescent lamp-ballast system, producing 50 percent more relative light output per watt than a 40W standard T-12 lamp. (Note, however, that this T-8 has a rated life of only 15,000 hours compared to 20,000 for the T-12, with both operating in rapid start mode).

T-8 lamps fit in the 4-ft T-12 lamp sockets, but require a different type of ballast. Standard T-12 fluorescent lamps operate at 430 mA, whereas a 32W T-8 operates at 265 mA. Both magnetic ballasts and high-frequency electronic ballasts (which further improve efficiency) are available. Electronic instant start ballasts are designed to operate three or four T-8 lamps in parallel so that when one lamp burns out, the rest continue to operate. These ballasts increase the system efficacy by 50 percent compared to the standard 40W fluorescents with magnetic ballasts.

Color Rendering Properties

Table 3 summarizes the color-rendering properties of various fluorescent lamps. Cool white lamps with halophosphate phosphors are the most commonly used because of their lower cost and higher efficiency as compared to deluxe cool white lamps (using halophosphate phosphor).

Applications

Table 4 lists various fluorescent lamps recommended for each type of application—retrofit, renovation, and new construction.

Table 3

Color-Rendering Properties of Various Fluorescent Lamps (With Halophosphate Phosphor)

Designation	Effect on "Atmosphere"	Colors Strengthened	Colors Weakened or Grayed	Remarks
Cool white	Neutral to fairly cool	Blue	Red, orange, yellow	Blends with natural daylight
Deluxe cool white	Neutral to fairly cool	All nearly equal	None appreciably	Simulates natural daylight
Warm white	Warm	Orange, yellow	Red, blue	Blends with incandescent light
Deluxe warm white	Warm	Red, orange, yellow, green	Blue	Simulates incandescent light

Table 4

Fluorescent Lamp Applications

Fluorescent Lamps	Retrofit	Renovation	New Construction
40W F40 T-12 CW	---[0]	Yes[0]	Yes[0]
40W F40 T-10	Yes[1]	Yes[1]	Yes[1]
34W F40 T-12 CW	Yes	No	No
32W F32 T-8 41K	Yes[2,3]	Yes[3]	Yes[3]

[0]Standard lamp
[1]Will provide higher light levels (15-25%)
[2]Good retrofit if also changing ballasts
[3]Most efficacious system

3 ADVANCED BALLAST SYSTEMS

Fluorescent ballasts are designed to operate *preheat, instant start*, or *rapid start* fluorescent lamps. *Preheat* operation uses a starter to preheat lamp filaments (which form a cathode) by initially sending the power through the filaments. Once the filaments are heated, the starter opens, and the ballast applies full voltage across the lamp. In *instant start* lamps, the filaments are not heated; rather, the ballast delivers a very high initial voltage to start the lamps. *Rapid start* lamp filaments are heated all the time during starting and while in operation. Some (cut-out) ballasts remove filament voltage after starting the lamps. Rapid start lamp-ballast systems are the most popular and the most commonly used 40W F40 lamps. The advantages of this type include smooth starting and longer lamp life.

Two types of ballasts are used today with fluorescent lamps: magnetic core-coil and electronic ballasts.

Magnetic Core-Coil

Magnetic core-coil ballasts also are known as *electromagnetic*, *magnetic*, or *core-coil* ballasts. These ballasts operate lamps at the nominal power distribution frequency of 60 Hz. The energy-efficient magnetic ballasts last for about 12 to 15 years (75,000 hours). High temperatures decrease their life while cooler temperatures extend it. Subclasses of ballasts are standard core-coil, energy efficient core-coil and heater cutout. The standard core-coil ballasts use aluminum wiring while the high efficiency core-coil ballasts have copper wiring and better magnetic materials that produce a 10 percent improvement in system efficacy. Federal law prohibits the use of the standard magnetic ballast. Heater cutout energy efficient ballasts are equipped with a cutout device that turns off cathode heaters in fluorescent lamps once the lamps are ignited and operating. Each heater cutout ballast requires 5 fewer watts with no change in light output. These ballasts are cost-effective and can be used with most 34W F40 T-12, 40W F40 T-12, and 40W F40 T-10 lamps.

Electronic Ballasts

Electronic ballasts incorporate advanced solid state circuitry that converts 60 Hz input frequency to a higher frequency, typically 25 to 40 kHz. They offer several advantages over conventional magnetic ballasts:

- lamp-ballast system efficacy improvements of 25 percent or more
- dissipation of significantly less heat
- quieter operation
- reduced flicker by incorporating good quality 60 Hz filters
- electronic dimming features.

Although electronic ballasts experienced premature failures when they were introduced a decade ago, today's technology is more reliable and far superior to earlier models. Many types of electronic ballasts are currently available, including: *instant start, rapid start, adjustable output*, and *full-range dimming* ballasts.

Electronic dimming features are especially advantageous because they can save up to 50 percent additional lighting system energy when used with certain control strategies. Energy-saving control strategies include: *scheduling, task tuning, lumen maintenance, daylight harvesting*, and *load shedding*.

Scheduling involves varying light levels in accordance with predicted operations. For example, lighting levels can be dimmed in the evenings when cleaning crews are working, because a lower lighting level is generally needed for such tasks.

Task tuning provides different amounts of light in different areas, depending on the tasks normally performed in that place. For example, lighting in hallways can be dimmed because difficult visual tasks are not performed there. Lighting levels can also be dimmed when video display terminal (VDT) tasks are being performed. (This strategy not only saves energy but also reduces glare and provides better visibility.)

Lumen Maintenance lowers the initial light levels to the maintenance level, reducing the power consumed. As lamps age, additional power is applied to maintain the light level.

Daylight harvesting involves using a photosensor in conjunction with an electronic dimmable ballast to reduce electric lighting levels when daylight is available (thus saving energy and avoiding overlighting) and to increase electric lighting when daylight is not available.

Load shedding is dimming lighting imperceptibly during peak demand periods to reduce utility demand charges.

4 FACTORS AFFECTING SYSTEM PERFORMANCE

Lighting system performance depends on many factors, including *lamp and ballast input/output characteristics*, *ballast factor*, *system efficacy*, *compatibility of system components*, *age of equipment*, *operating temperatures*, and *maintenance*.

Lamp and Ballast Input/Output Characteristics

Lamp and ballast input/output characteristics can affect lighting system reliability, electrical power quality and worker productivity. The characteristics that affect lighting system reliability include *light regulation*, *lamp current crest factor*, and *filament voltage*. Those that affect electrical power quality include *power factor* and *harmonic distortion*. Experiments have indicated that some portion of the population is adversely affected by *flicker*, a characteristic that can reduce productivity.

Light Regulation

Light regulation is defined by the variation in light output as a function of change in input voltage. Normally ballasts are designed to operate at a specified voltage, ±10 percent. Highly regulated ballasts provide constant light levels over the ±10 percent range of input voltages. Loosely regulated systems require higher average light levels to compensate for conditions when the input voltage is below the design voltage.

Tests conducted by the Lawrence Berkeley Laboratory (LBL) for this study show a wide range of light regulation (1.2 to 16 percent) for various electronic ballasts. Although highly regulated ballasts are the most effective choice in applications requiring constant light output, loosely regulated ballasts can be used in certain dimming applications.

Lamp Current Crest Factor

Lamp current crest factor is a ratio of peak lamp current to root mean square (rms) lamp current. In tests conducted by LBL, this ratio typically ranged between 1.3 and 2 for various lamps. Although most lamps had current crest factors below or equal to the American National Standards Institute (ANSI) recommended limit of 1.7 (ANSI C82.1-1985), some lamp-ballast systems (e.g., EBT ballasts combined with T-8 lamps) had current crest factors between 1.7 and 1.8. High lamp current crest factors reduce lamp life. The ANSI limit of 1.7 is a consensus such that the standard 40W F40 T-12 lamp will have a 20,000-hour life when operated 3 hours on and 20 minutes off.

Filament Voltage

Filament voltage significantly impacts lamp life. Lamps operated at full light output with no filament power have a derated life of 25 percent (15,000 hours) compared to lamps operated in the rapid start mode (20,000 hours). In most cases, removing filament power is a cost-effective strategy.

However, in the dimmed mode, reduced filament power will drastically reduce lamp life. Tests conducted by LBL have shown that 40W F40 T-12 lamps failed after several hundred hours of operation when operated at 20 percent of full light output with a filament voltage of less than 1 v.

Most electronic ballasts deliver filament voltages ranging between 1.7 and 3.6 V, depending on the type of lamp used. However, recent LBL tests show that some ballasts (e.g., Etta ballasts) deliver filament voltages as high as 5.5. These values surpass ANSI-recommended maximum filament voltage of 4.0. Such excessive voltages can not only waste energy but can shorten lamp life by evaporating the coating materials from the filament.

Power Factor

Power factor is the ratio of real power (kW) to apparent power (kVA) in any electrical system. Apparent power is the vector sum—not the arithmetical sum—of the real power and the reactive power. Electric utilities must provide both real and reactive power for their customers. Reactive power does not register on a kilowatt meter, but producing it still requires the utility to invest additionally in generating, transmission, and distribution facilities. Many utilities make up for the expense of producing reactive power by including power factor provisions in their rates. Many utilities define low power factor as anything less than 0.85, or 85 percent. High power factor fluorescent lamp-ballast systems have power factors equal or exceeding 90 percent.

Harmonic Distortion

Harmonic distortion is caused by mixtures of higher frequencies reflected back on the regular 60 Hz current supplied by the utility. These higher frequencies produce jagged waveshapes that are quite different from the smooth sinusoidal waveshapes characteristic of the original current. Both magnetic and electronic ballasts generate harmonics that have been of concern to the utilities. These distorted waveshapes in turn produce a decline in power factor. Using a capacitor will not correct power factor problems caused by irregular waveshapes. Harmonic distortion can be reduced to acceptable levels by an electronic ballast's circuit design.

Tests conducted by LBL for this study show that harmonic distortion generated by electronic ballasts can vary from 5 percent to well over 33 percent of the fundamental current. In fact, several electronic ballasts generate less harmonic currents than magnetic ballasts, and most manufacturers hold harmonic distortion to levels well below those recommended by ANSI (total harmonic distortion less than 32 percent). For rebates, some utilities require third harmonic distortion to be 20 percent or less. All currently available electronic ballasts meet this requirement. The low harmonic ballasts must be specified.

Flicker

Flicker is a measure of modulation of a system's light output. Flicker is defined as the difference between the maximum and minimum intensities divided by their sum, and is expressed as a percentage. Because it can cause discomfort and reduce worker productivity, eliminating flicker is an important goal in any lighting system retrofit.

Tests conducted by LBL for this study showed that, when operated at high frequency with an electronic ballast, cool white fluorescent lamps produce only 0 to 6 percent flicker. In contrast, cool white fluorescent lamps operating with magnetic ballasts at 60 Hz can have a flicker of up to 33 percent.

Ballast Factor

Ballast factor defines the relative light output provided by a lamp-ballast system with respect to the manufacturer's rated light output for the specified lamp. This is an important factor because it determines the most appropriate applications for a given ballast. A high ballast factor may be the most economical for renovations and new construction because fewer ballasts and lamps will be required to provide a specific level of illumination. A low ballast factor can be useful in retrofitting over-illuminated spaces.

Tests conducted by LBL in this investigation show that an electronic ballast that can provide 93 percent of the rated light output for a standard 40W F40 fluorescent lamp produces only 90 percent of rated output when used with a 34W F40 fluorescent lamp. A magnetic ballast that has a 96 percent ballast factor with the standard lamp may have only a 88 percent ballast factor when operating the energy-saving lamp. It is important to note that the same ballast will have different ballast factors with standard 40W F40 and energy-saving 34W F40 fluorescent lamps.

Energy-saving lamps produce lower ballast factors than standard lamps because they present a different load to the ballast. The lower ballast factor represents an equal reduction in the power required and the light provided by a 34W F40 lamp. This maintains the system relationship between input power and lumen output. The ballast factor is different for the different lamps, but the relative efficacy of the two lamp-ballast systems remains the same.

System Efficacy

System efficacy describes how effectively the lighting system converts electric energy into visible light. Efficacy is measured in lumens of output per watt of input (lm/W). The 32W F32 T-8 fluorescent lamps operated by instant start electronic ballasts can achieve system efficacies over 90 lm/W for an improvement of about 46 percent over standard 40W F40 T-12 cool white lamps operated by standard magnetic ballasts.

Compatibility of System Components

Lighting system components must be compatible if the system is to perform its functions effectively and economically. For example, 40W F40 T-10 lamps can generally be used to retrofit 40W F40 T-12 lamps in areas that require increased light output. However, some 40W F40 T-10 lamps may not start properly with the 40W F40 T-12 ballast over the entire voltage range. If standard 40W F40 T-12 lamps are replaced with 32W F32 T-8 lamps, the replacement lamps will not function properly. Likewise, replacing a 32W F32 T-8 system with the 40W F40 T-12 lamps will cause problems. In all cases, compatibility of system components must be verified before any retrofits are made. Optimal system performance can only be assured when all the components operate together in an efficient manner without compromising lighting quality, function, and cost-effectiveness.

Age of Equipment

New lighting equipment often uses different design concepts and technologies than those used by older equipment. These design differences can adversely affect system performance in retrofit situations. System performance of retrofits also can be impaired because of lower reliability inherent in older equipment. In most cases, it will prove to be more cost-effective to replace the entire system that is at or near the end of its useful life than simply to change a single component.

Operating Temperatures

Operating temperatures can affect both lamp life and system efficacy. The efficacy of fluorescent lamps tends to decrease as their temperature increases above 104 °F. In particular, the efficacy of lamps operated by a standard magnetic ballast is lowered by 15 percent when the temperature of the lamp wall rises from 104 to 140 °F. The same lamps show only a 7 percent decline in efficacy when operated by an electronic ballast—about half the impact. Use of electronic ballasts makes the performance of a fluorescent lighting system less sensitive to the effects of elevated temperature.

Maintenance

Lighting is designed and installed to perform a variety of functions. Its ability to perform these functions can be seriously impaired when the equipment is not adequately maintained. Dirt that builds up on the luminaire and lamp surfaces restricts light distribution and can affect distribution patterns. The following simple techniques should provide adequate maintenance: cleaning luminaires, lamps, and lenses regularly; following relamping schedules; cleaning surfaces in the illuminated space; and using other maintenance to improve the quantity and quality of illumination created by the existing system, and to yield cost and energy savings.

5 SELECTING A RETROFIT SYSTEM

Many fluorescent lighting products are available from many different manufacturers. Selecting a lamp-ballast system has become a complex task. To simplify the selection process, two decision matrices were developed, one applicable to a two-lamp fluorescent fixture (Figure 2), and the other to a four-lamp fixture (Figure 3).

The decision matrices are based on results of tests performed by LBL on several commonly available lamp-ballast combinations. The family of lamps tested included the F40 T-12, F40 T-10, and F32 T-8 (manufactured by Sylvania). Ballasts tested with these lamps in various combinations included both standard magnetic core-coil ballasts manufactured by General Electric Co. and Advance, and electronic ballasts manufactured by MagneTek, Etta Industries, and EBT. Lamp-ballast system tests were conducted at standard ANSI conditions of 77 °F and at a higher temperature representing the thermal environment of a four-lamp 2x4-ft fixture (°F = [°C × 1.8] +32).

The following steps are required to identify the most effective lamp-ballast system options for retrofit:

1. Determine type of lamp and ballast systems in use through site survey and visual inspection.

2. Establish selection criteria for new lamp-ballast system in terms of light output. Should the new system produce the same amount of light? Should it produce less light or more light? How much more or less, in percent?

3. Identify the existing lamp-ballast system on the appropriate decision matrix (Figure 2 or 3). Note that lamp-ballast systems are located on the vertical axis, listed in terms of ascending values of system efficacy.

4. Once the existing system has been located, follow that row to the right, moving diagonally along the top number of each box to the boxes containing asterisks (*). These boxes highlight the options that will produce equal light output. The bottom number in each box represents relative input power in percent as compared to the existing system. If the criteria established for light output in Step 3 is for "more" or "less" light, then move to those boxes with relative light output values equal or similar to the desired value of the light output as compared to the existing system. Note that a value of 102 means that the option will produce 2 percent greater light output than the existing system.

The identification of the retrofit options can be determined by moving diagonally towards the left and downwards from the box.

5. Evaluate different options in terms of light output characteristics, energy use and system efficacy. Identify the option that best meets your light output criteria (established in Step 2) and is the most energy-efficient.

6. Evaluate initial cost-effectiveness of the option (Chapter 6).

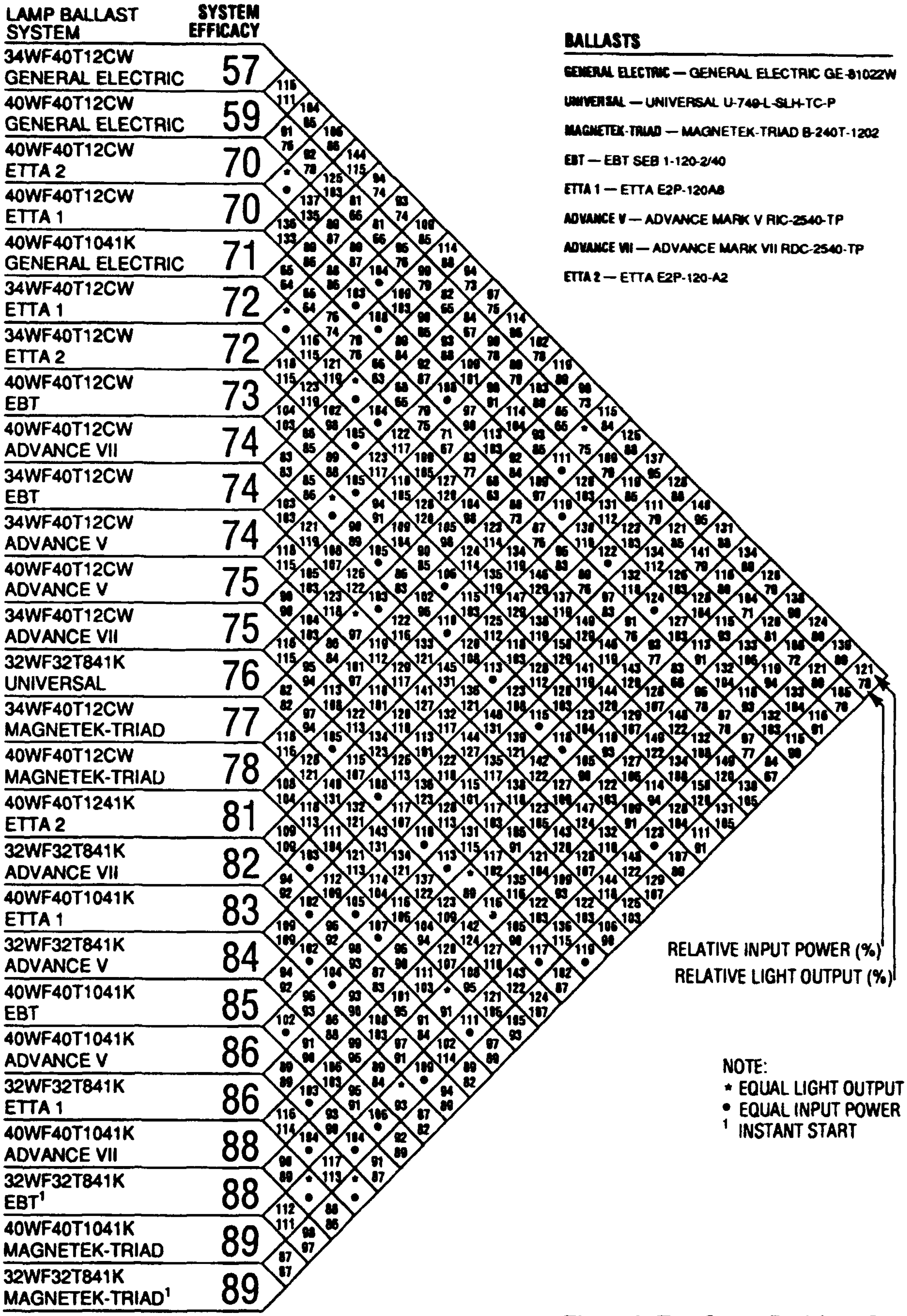

Figure 2. Two-Lamp Decision Matrix.

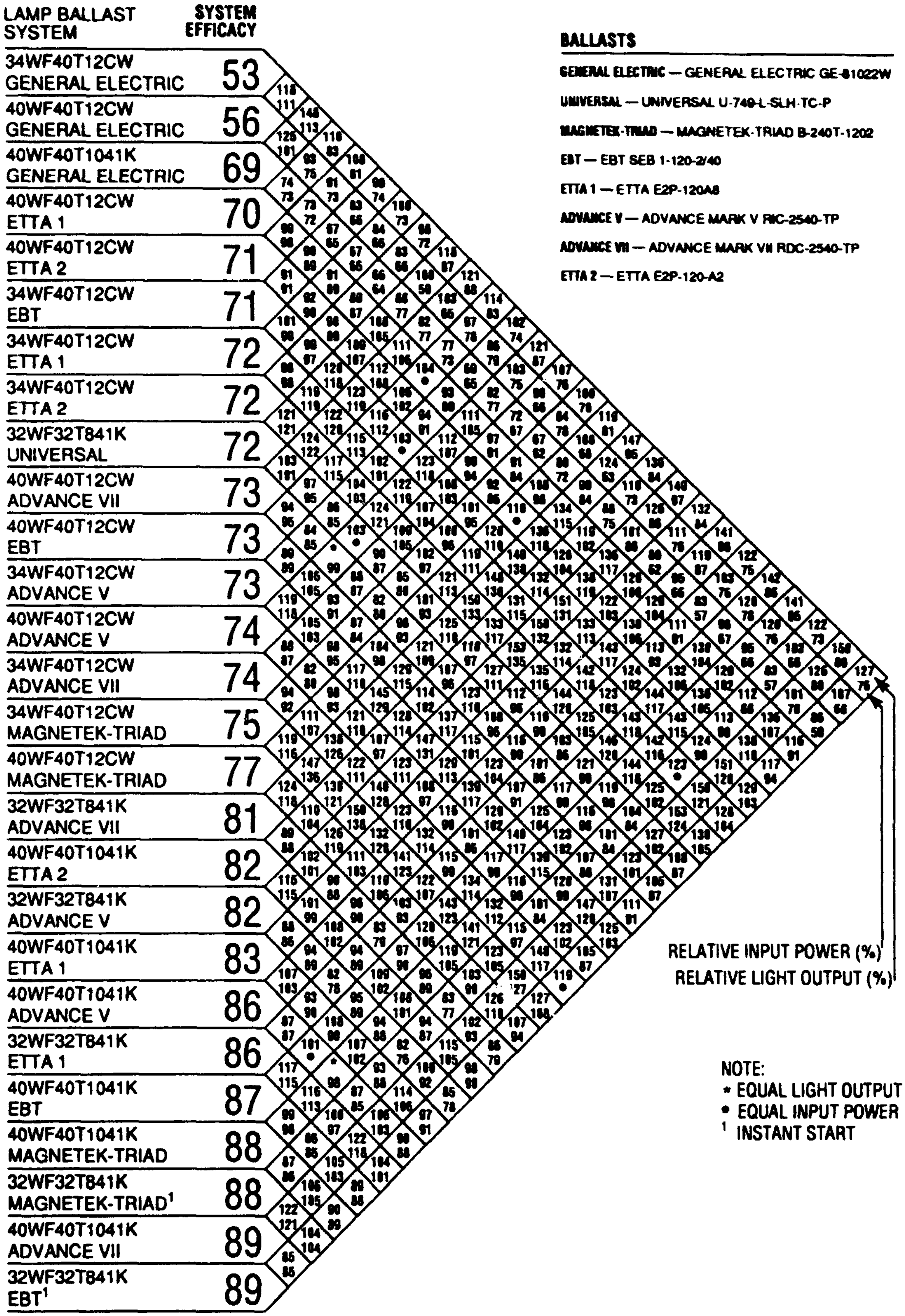

Figure 3. Four-Lamp Decision Matrix.

6 EVALUATING COST-EFFECTIVENESS

Once the various lamp-ballast system options have been identified, the next step is to evaluate the cost and benefits of each option. Life-cycle costing methods can help obtain an accurate picture of cost. Life-cycle costing requires a calculation of all relevant costs over the life of the system involved, including:

- initial costs associated with purchase and installation
- operating costs
- maintenance costs of the equipment over its useful life.

Because a life-cycle costing analysis can be time-consuming, two simple techniques can be used for *initial* evaluation of alternative options. These are simple payback and return on investment (ROI).

Simple Payback

The simple payback technique can help to evaluate and quickly narrow the many options before doing the required life-cycle costing for a final effective choice. Simple payback identifies the length of time required for an investment to pay for itself. By dividing the initial cost of a system option by its estimated annual dollar savings, the length of time, in years, it will take to pay for the item can be determined:

$$\text{Simple payback} = \frac{\text{Initial Cost}}{\text{Annual Savings}} \qquad \text{[Eq 1]}$$

If a system that costs \$1000 to install saves \$500 per year, its simple payback is 2.0 years. If it saves \$750 per year, payback occurs in 1.33 years, or 16 months.

Annual dollar savings can be estimated by multiplying the total input power savings (of all retrofitted fixtures) by the annual hours of system operation and the average electricity rate (¢/khr). Total system input power savings is the difference between input power requirements of the retrofit and the existing system. Tables 5 and 6 can be used to determine these savings for two- or four-lamp fixtures.

Return on Investment

Return on investment (ROI)—the reciprocal of simple payback—is expressed as a percentage, so that an evaluated technology with an ROI of 100 percent will pay for itself in savings in 1 year:

$$\text{ROI} = \frac{\text{Annual Savings}}{\text{Initial Cost}} \qquad \text{[Eq 2]}$$

A system that costs \$1000 to install and saves \$500 per year will have an ROI of 50 percent:

$$\frac{\$500}{\$1000} = 0.50 = 50 \text{ percent}$$

Table 5

Total Input Power (W) for Various Lamp-Ballast Systems for a Two-Lamp Fixture

Ballasts	40W F40 T-12 CW	40W F40 T-10 41K	34W F40 T-12 CW	32W F32 T-8 41K
General Electric GE-81022W	89	92	80	—
Universal U-749-L-SLH-TC-P	—	—	—	71
MagneTek-Triad B-240T-1202	67	71	58	62*
EBT SEB 1-120-2/40	68	70	58	64*
Etta E2P-120A8	69	70	59	63
Advance Mark V RIC-2540-TP	69	71	60	76
Advance Mark VII RDC-2540-TP	70	72	62	76
Etta E2P-120-A2	68	70	59	—

*Instant start

Table 6

Total Input Power (W) for Various Lamp-Ballast Systems for a Four-Lamp Fixture

Ballasts	40W F40 T-12 CW	40W F40 T-10 41K	34W F40 T-12 CW	32W F32 T-8 41K
General Electric GE-81022W	170	173	153	—
Universal U-749-L-SLH-TC-P	—	—	—	133
MagneTek-Triad B-240T-1202	124	130	107	112*
EBT SEB 1-120-2/40	127	132	113	116*
Etta E2P-120A8	127	128	112	115
Advance Mark V RIC-2540-TP	133	132	113	146
Advance Mark VII RDC-2540-TP	134	136	110	148
Etta E2P-120-A2	124	129	110	—

*Instant start

7 SUMMARY

Fluorescent lamps are manufactured in a variety of shapes and sizes, and a range of specifications. (Chapter 2) This study investigated the following types of fluorescent lamps:

- energy-efficient 34W F40 T-12 lamps
- energy-efficient 32W F40 T-12 lamps
- high-efficiency phosphor lamps
- 40W F40 T-10 lamps
- 32W F32 T-8 lamps.

Two types of ballasts are used today with fluorescent lamps: Magnetic core-coil and electronic ballasts. Energy-efficient magnetic ballasts can be long-lasting (about 12 to 15 years, or 75,000 hours), but electronic ballasts offer several advantages over conventional magnetic ballasts:

- lamp-ballast system efficacy improvements of 25 percent or more
- dissipation of significantly less heat
- quieter operation
- reduced flicker by incorporating good quality 60 Hz filters
- electronic dimming features.

Electronic dimming features can save up to 50 percent additional lighting system energy when used with certain control strategies, including: scheduling, task tuning, lumen maintenance, daylight harvesting, and load shedding. (Chapter 3)

Lighting system performance depends on many factors, including lamp and ballast input/output characteristics, ballast factor, system efficacy, compatibility of system components, age of equipment, operating temperatures, and maintenance.

The following steps can help identify the most effective lamp-ballast system options for retrofit applications:

1. Determine type of lamp and ballast systems in use.
2. Establish selection criteria for new lamp-ballast system in terms of light output.
3. Use a decision matrix (pp 19,20) to identify the existing lamp-ballast system.
4. Identify comparable systems in terms of light output and input power.
5. Identify the best option in terms of light output, energy use, and system efficacy. (Chapter 5)
6. Evaluate initial cost-effectiveness of the option (Chapter 6).

USACERL DISTRIBUTION

Chief of Engineers
ATTN: CEHEC-IM-LH (2)
ATTN: CEHEC-IM-LP (2)
ATTN: CECG
ATTN: CERD-M
ATTN: CECC-P
ATTN: CERD-L
ATTN: CECW-P
ATTN: CECW-PR
ATTN: CEMP-E
ATTN: CEMP-C
ATTN: CECW-O
ATTN: CECW
ATTN: CERM
ATTN: CEMP
ATTN: CERD-C
ATTN: CEMP-M
ATTN: CEMP-R
ATTN: CERD-ZA
ATTN: DAEN-ZCM
ATTN: DAEN-ZCE
ATTN: DAEN-ZCI

CEHSC
ATTN: CEHSC-F 22060
ATTN: CEHSC-TT 22060
ATTN: CEHSC-ZC 22060
ATTN: DET III 79906

US Army Engr District
ATTN: Library (40)

US Army Engr Division
ATTN: Library (13)

INSCOM
ATTN: IALOG-I 22060
ATTN: IAV-DEH 22186

USA TACOM 48397
ATTN: AMSTA-XE

Defense Distribution Region East
ATTN: DDRE-WI 17070

HQ XVIII Airborne Corps 28307
ATTN: AFZA-DEH-EE

4th Infantry Div (MECH)
ATTN: AFZC-FE 80913

Fort Pickett 23824
ATTN: AFZA-FP-E

Tobyhanna Army Depot 18466
ATTN: SDSTO-EH

US Army Materiel Command (AMC)
Redstone Arsenal 35809
ATTN: DESMI-KLF
Jefferson Proving Ground 47250
ATTN: STEJP-LD-F/DEH
Letterkenny Army Depot
ATTN: SDSLE-ENN 17201
Pueblo Army Depot 81008
ATTN: SDSTE-PUI-F
Dugway Proving Ground 84022
ATTN: STEDP-EN
Tooele Army Depot 84074
ATTN: SDSTE-ELF
Yuma Proving Ground 85365
ATTN: STEYP-EH-E
Tobyhanna Army Depot 18466
ATTN: SDSTO-EH
Seneca Army Depot 14541
ATTN: SDSSE-HE
Aberdeen Proving Ground
ATTN: STEAP-DEH 21005
Sharpe Army Depot 95331
ATTN: SDSSH-E
Fort Monmouth 07703
ATTN: SELFM-EH-E
Savanna Army Depot 61074
ATTN: SDSLE-VAE
Rock Island Arsenal
ATTN: SMCRI-EH
ATTN: SMCRI-TL
Watervliet Arsenal 12189
ATTN: SMCWV-EH
Red River Army Depot 76102
ATTN: SDSRR-G
Harry Diamond Lab
ATTN: Library 20783
White Sands Missile Range 88002
ATTN: Library
Corpus Christi Army Depot
ATTN: SDSCC-ECD 78419

FORSCOM
ATTN: Facilities Engr (12)
Fort Bragg 28307
ATTN: AFZA-DE
Fort Campbell 42223
ATTN: AFZB-DEH
Fort McCoy 54656
ATTN: AFZR-DE
Fort Stewart 31314
ATTN: AFZP-DEF
Ft Buchanan 00934
ATTN: Envr Office
Ft Devens 01433
ATTN: AFZD-DE
Fort Drum 13602
ATTN: AFZS-EH-E
Fort Irwin 92310
ATTN: AFZJ-EH
Fort Hood 76544
ATTN: AFZF-DE-AES Engr
Fort Meade 20755
ATTN: AFKA-ZI-EH-A

6th Infantry Division (Light)
ATTN: APVR-DE 99505
ATTN: APVR-WF-DE 99703

National Guard Bureau 20310-2500
ATTN: NGB-ARI

Fort Belvoir 22060
ATTN: CETEC-IM-T
ATTN: CECC-R 22060
ATTN: Engr Strategic Studies Ctr
ATTN: Australian Liaison Office

USA Natick RD&E Center 01760
ATTN: STRNC-DT
ATTN: DRDNA-F

TRADOC
ATTN: DEH (13)
Fort Monroe 23651
ATTN: ATBO-G
Carlisle Barracks 17013
ATTN: ATZE-DIS
Fort Eustis 23604
ATTN: DEH
Fort Chaffee 72905
ATTN: ATZR-ZF
Fort Sill 73503
ATTN: ATZR-E

US Army Materials Tech Lab
ATTN: SLCMT-DEH 02172

USARPAC 96858
ATTN: DEH
ATTN: APEN-A

SHAPE 09705
ATTN: Infrastructure Branch LANDA

Area Engineer, AEDC-Area Office
Arnold Air Force Station, TN 37389

HQ USEUCOM 09128
ATTN: ECJ4-LIE

AMMRC 02172
ATTN: DRXMR-AF
ATTN: DRXMR-WE

CEWES 39180
ATTN: Library

CECRL 03755
ATTN: Library

USA AMCOM
ATTN: Facilities Engr 21719
ATTN: AMSMC-IR 61299
ATTN: Facilities Engr (3) 85613

USAARMC 40121
ATTN: ATZIC-EHA

Military Traffic Mgmt Command
ATTN: MTEA-GB-EHP 07002
ATTN: MT-LOF 20315
ATTN: MTE-SU-FE 28461
ATTN: MTW-IE 94626

Fort Leonard Wood 65473
ATTN: ATSE-DAC-LB (3)
ATTN: ATZA-TE-SW
ATTN: ATSE-CFLO
ATTN: ATSE-DAC-FL

Military Dist of WASH
Fort McNair
ATTN: ANEN 20319

USA Engr Activity, Capital Area
ATTN: Library 22211

Norton AFB 92409
ATTN: Library

US Army ARDEC 07806
ATTN: SMCAR-ISE

Charles E Kelly Spt Activity
ATTN: DEH 15071

Engr Societies Library
ATTN: Acquisitions 10017

Defense Nuclear Agency
ATTN: NADS 20305

Defense Logistics Agency
ATTN: DLA-WI 22304

Walter Reed Army Medical Ctr 20307

US Military Academy 10996
ATTN: MAEN-A
ATTN: Facilities Engineer
ATTN: Geography & Envr Engrg

416th Engineer Command 60623
ATTN: Gibson USAR Ctr

Naval Facilities Engr Command
ATTN: Facilities Engr Command (8)
ATTN: Division Offices (11)
ATTN: Public Works Center (8)
ATTN: Naval Constr Battalion Ctr 93043
ATTN: Naval Civil Engr Laboratory (3) 93043

US Army HSC
Fort Sam Houston 78234
ATTN: HSLO-F
Fitzsimons Army Medical Ctr
ATTN: HSHG-DEH 80045

Tyndall AFB 32403
ATTN: AFESC Program Ofc
ATTN: Engrg & Srvc Lab

USA TSARCOM 63120
ATTN: STSAS-F

American Public Works Assoc. 64104-1806

US Army Envr Hygiene Agency
ATTN: HSHB-ME 21010

US Gov't Printing Office 20401
ATTN: Rec Sec/Deposit Sec (2)

Nat'l Institute of Standards & Tech
ATTN: Library 20899

Defense Tech Info Center 22304
ATTN: DTIC-FAB (2)

302
03/93

This publication was reproduced on recycled paper.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1993—3510-S/80035